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ELECTRON LINEAR ACCELERATOR PRODUCTION OF OXYGEN-15,(U)
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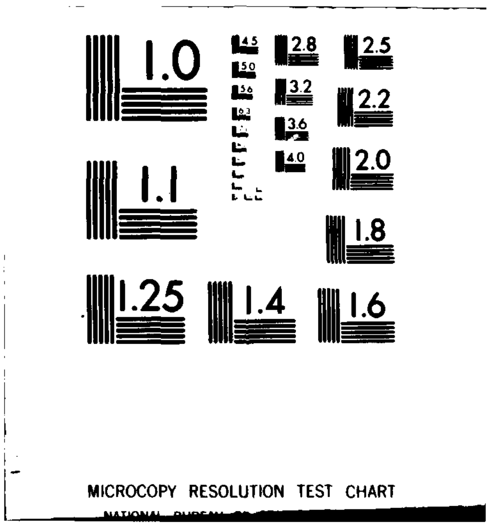
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ELECTRON LINEAR ACCELERATOR PRODUCTION OF OXYGEN-15

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An electron linear accelerator was used to produce gaseous oxygen-15 by bremsstrahlung irradiation of hydrogen peroxide-water solutions. With helium as a sweep gas, it was possible to achieve ^{15}O activities of 24 mCi per liter of gas. Carbon-11, the only detectable radioactive contaminant, constituted less than 0.2% of the activity when 30-MeV electrons were used. Transfer of ^{15}O to blood by a simple bubbling technique resulted in blood activities of about 85 μCi/cc of blood.

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INTRODUCTION

Oxygen-15 is a short-lived (2.05-min half-life) radioisotope that decays by positron emission with subsequent 0.511-MeV annihilation radiation. It has been used extensively for *in vivo* studies by inhalation of radioactive gas *(1-4)* or by transfer of the ^{15}O to a blood sample, which is then injected *(5,6)*. The cyclotron is usually used in ^{15}O production, most often via the $^{14}N(d,n)^{15}O$ reaction. The cyclotron-induced reactions $^{16}O(p,pn)^{15}O$ *(7)* and $^{16}O(^{3}He,^{4}He)^{15}O$ *(3)* have also been investigated. Production of this radioisotope is also possible using an electron accelerator. The high-energy electron beam is converted to an X ray beam by means of a bremsstrahlung converter, and the reaction $^{16}O(\gamma,n)^{15}O$ (threshold 15.7 MeV) is utilized. Meyer *(8)* used bremsstrahlung irradiation of a pressurized gaseous O_2 target to produce ^{15}O for dynamic lung-function studies. Welch *(9)* has investigated the production of radioactive O_2, one atom of which is ^{15}O, by bremsstrahlung irradiation of water. The mechanism is:

$$\gamma + H_2O \longrightarrow {}^{15}O + n + H_2$$

$$^{15}O + H_2O \longrightarrow \left\{H - O - {}^{15}O - H\right\}^* \longrightarrow O^{15}O + H_2$$

Here $\{---\}^*$ indicates an excited molecular state.

During the (γ,n) interaction on an oxygen atom in a water molecule, the molecular bonds are broken, and free ^{15}O results. This free oxygen atom interacts with a water molecule to form an excited state of hydrogen peroxide, which then decomposes into $O^{15}O$ and H_2. The radioactive oxygen gas is then liberated from the liquid. A modification of this method is described here.

METHOD OF PRODUCTION

A high-energy bremsstrahlung beam was produced by directing the electron beam from the AFRRI linear accelerator (LINAC) onto a water-cooled tantalum

converter of thickness 11.8 g/cm^2. The liquid target was contained in an aluminum cylinder, the approximate dimensions of which are given in Figure 1. The cylinder was filled with approximately 2 liters of distilled water for the first irradiations. Later runs were made with water-hydrogen peroxide solutions of various concentrations. Helium was used to flush the radioactive O_2 from the liquid and move it through the system in a single pass. The helium was piped into the cylinder and released through the liquid by means of a perforated tube. A flow rate of about 1.0 liters of helium per minute was found to be sufficient. Cold traps of liquid nitrogen were used to remove water vapor and CO_2 from the gas. After normal irradiation times of 8-10 min (4-5 ^{15}O half-lives), samples of gas were collected at room temperature and pressure for analysis. Activities were measured using an NaI scintillation detector, and an analysis of the activity-time data was accomplished graphically and with a computer fitting program based on W. R. Smith's SEARCH subroutine *(10)*.

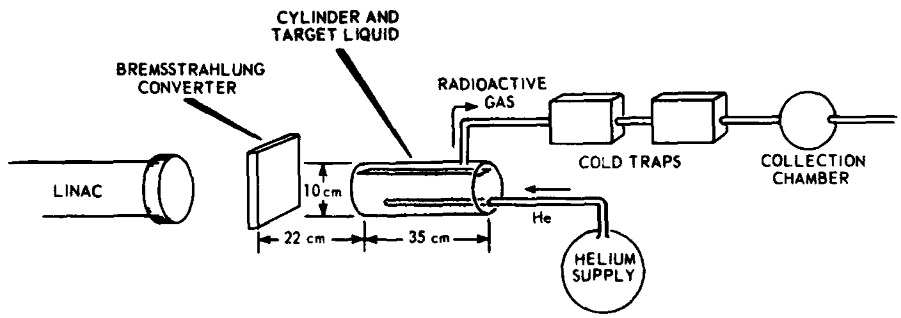

Figure 1. Irradiation arrangement

RESULTS OF ^{15}O PRODUCTION

The irradiation of distilled water (with bremsstrahlung developed from a 45-MeV electron beam) produced ^{15}O activities that were strongly time-dependent. Initial samples had low activity, while samples collected after many irradiations of the same target water demonstrated order-of-magnitude increases in

activity. This increase was presumed to be due to the hydrogen peroxide buildup in the water during the irradiation process. It was therefore decided to investigate the use of water-hydrogen peroxide solutions as targets. The resulting ^{15}O activities per liter of gas are summarized in Table 1. All activities are normalized to a pulse-repetition rate of 60 pulses per second, a pulse width of 5 μsec, and a peak beam current of 0.35 A for 45 MeV, 1.0 A for 30 MeV.

TABLE 1. GAS ACTIVITIES

Electron Energy (MeV)	Percent H_2O_2	Average ^{15}O Activity (mCi/L)	Average $^{15}O/^{11}C$ Ratio
45	3	13	40
45	6	24	40
30	6	22	550
30	12	24	580

A 3% H_2O_2-water target irradiated at 45 MeV demonstrated a slight activity buildup with the number of irradiations, but equilibrium was soon established at about 13 mCi/liter. Doubling the amount of H_2O_2 in the target liquid to 6% resulted in an activity of 24 mCi/liter with no detectable activity buildup. In both cases, ^{11}C, a positron emitter with half-life of 20.4 min, was produced by the $^{16}O(\gamma,n\alpha)^{11}C$ reaction (threshold 25.9 MeV) in an abundance of about 2.5% of the ^{15}O activity. The production of ^{13}N (positron emitter with half-life 10.0 min) via (γ,nd) or (γ,t) reactions on ^{16}O was not detected. To reduce the undesirable ^{11}C activity, the electron energy was reduced to 30 MeV. Irradiations of 6% and 12% H_2O_2-water at this lower energy gave activities of about 22-24 mCi/liter with ^{11}C contamination of less than 0.2%. With the 6% and 12% targets, the activities showed no significant increases or decrease for successive irradiations of the same target.

One method of increasing the activity of the gas is to use a closed loop system, wherein the helium makes multiple passes through the target liquid during the irradiation *(14)*. In such an arrangement the theoretical upper limit on activity, A, is given by:

$$A = \frac{A_o}{1 - e^{-\lambda T}}$$

where A_o = activity achieved in one pass,

λ = ln 2/(half-life) = decay constant of ^{15}O,

T = time required for one pass through the system.

If the flow rate is one liter per minute for one liter of helium gas, $A = 3.5\ A_o$. Thus, when A_o = 24 mCi, a maximum activity of about 83 mCi could be achieved.

RESULTS OF ^{15}O TRANSFER TO BLOOD

The transfer of ^{15}O to blood was investigated by allowing the radioactive gas to bubble through a vertical column of blood in 1.6-cm-diameter glass tubing, a method similar to that used by Ter-Pogossian et al. *(5)*. Small glass beads were placed in the tubing to break up the gas bubbles and increase gas-blood contact area. The blood was heparinized monkey blood that was deoxygenated before the irradiation by passing helium gas through it. The radioactive gas was passed through the blood for a period of 7-10 min during the irradiation. Samples of blood were then removed for analysis. The average blood activities for 6% and 12% H_2O_2-water solutions were 84 μCi/cc at 45 MeV and 85 μCi/cc at 30 MeV, where each activity was normalized as previously indicated.

CONCLUSIONS

Table 2 gives representative activities used in various types of experiments involving ^{15}O. It is seen that the LINAC-produced ^{15}O activity is sufficient for most inhalation type experiments. For long inhalation (i.e., inhalation for a period of 7-10 min), the radioactive gas can be diluted with air to achieve the desired activity. The blood activity achieved using the simple blood-bubbling technique described here appears to be about one order of magnitude smaller than that required for blood-injection experiments. An improved oxygen transfer

TABLE 2. BIOLOGICAL EXPERIMENTS INVOLVING OXYGEN-15

Experimenter, Year	Type Experiment	^{15}O Activity Used
Tilbury, 1971 *(3)*	Long inhalation, O_2, lung, dog	≤ 20 mCi/liter gas
Jones, 1976 *(12)*	Long inhalation, O_2, brain, human	2 mCi/liter gas
Hoop, 1976 *(4)*	Long inhalation, O_2, brain, human	0.5 mCi/liter gas
Dyson, 1958 *(1)*	Single breath, O_2, lung, human	2 mCi/liter gas
Taplin, 1976 *(13)*	Single breath, CO, lung, dog	150 mCi/liter gas
Kenny, 1976 *(7)*	Single breath, CO_2, heart, human	800 mCi/liter gas
Ter-Pogossian, 1969 *(5)*	Blood injection, brain, human	1 mCi/cc blood
Eichling, 1975 *(6)*	Blood injection, brain, monkey	1 mCi/cc blood

technique [e.g., use of a permeator tube or a tonometer *(13)*] should significantly increase the blood activity.

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